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OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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Articles PAGE

The Optical Parts of the 72 inch Telescope. - - *J. S. Plaskett* 177
Dr. John A. Brashear - - - - - *Frank C. Jordan* 200
Sun Dials - - - - - - - - - - *Otto Klotz* 205

Meetings of the Society

At Toronto, April 20 and May 4 - - - *J. A. Pearce* 211

Notes from the Meteorological Service

Temperature, Precipitation, Earthquake Records - - - 213

Notes and Queries

A Huge Meteor reported in Oklahoma; Publications Received; Members of National Committees - - - - *C. A. C.* 218

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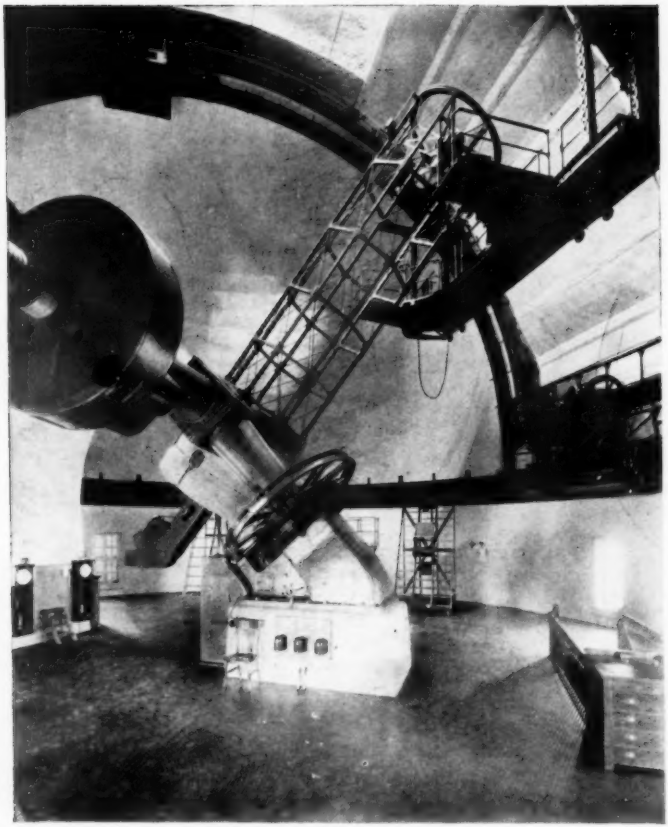
Mrs. W. Wilton, 117 Boyle St., Montreal, wish to sell a 4¼ inch refractor, with finder and 5 eyepieces.

The Editor wishes to learn of a 2 or 2½ inch refractor, preferably on a tripod, for sale.

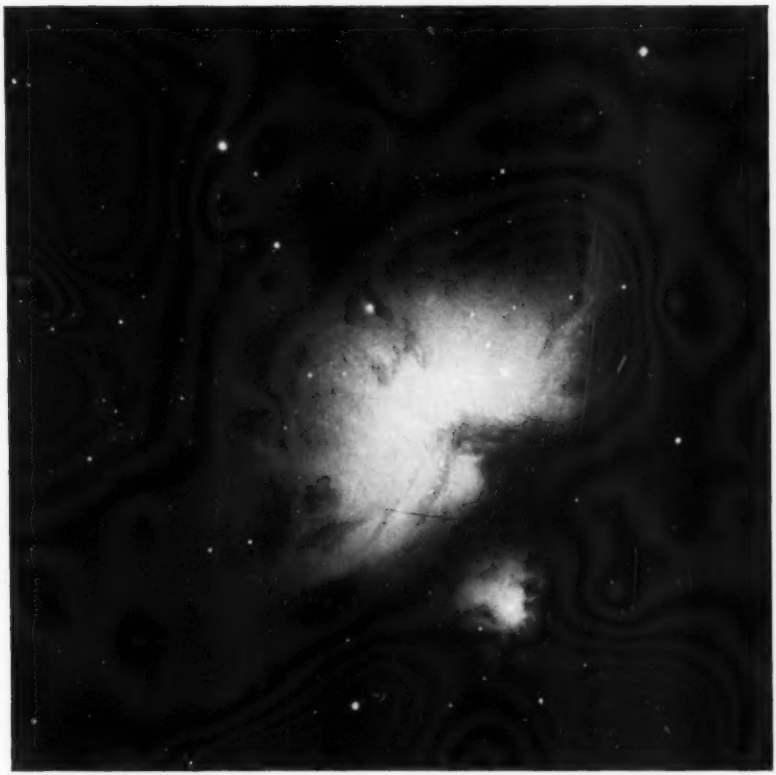
PLATE III.



TELESCOPE AND PLATFORM IN POSITION FOR DIRECT PHOTOGRAPHY, SHOWING INSULATING COVERING.

Journal of the Royal Astronomical Society of Canada, 1920.

PLATE IV.

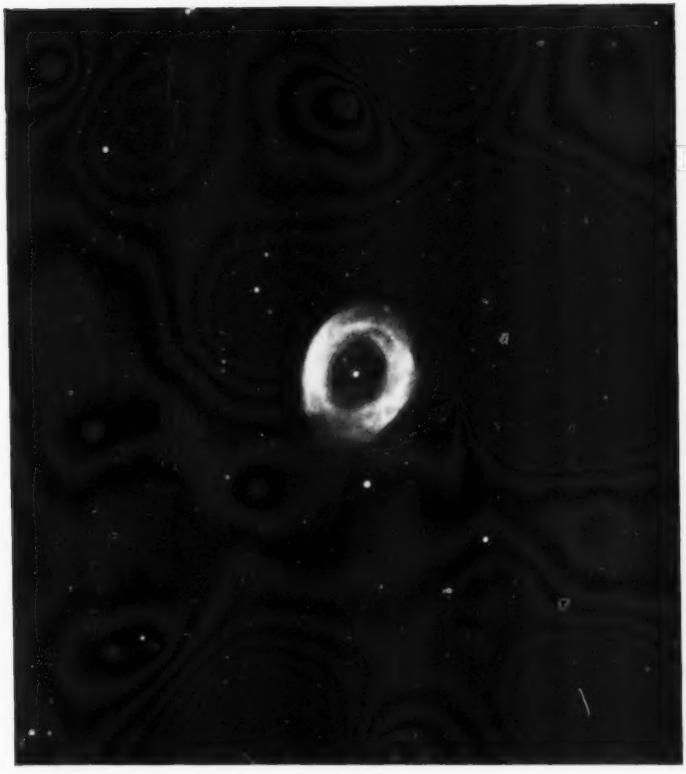


GREAT NEBULA IN ORION.

Exposure 25^{m} Enlargement 1.3 diam.

Journal of the Royal Astronomical Society of Canada, 1920.

PLATE V.



RING NEBULA IN LYRA.

Exposure 30^{m}, Seed 23 Plate. Enlargement 6 diam.

Journal of the Royal Astronomical Society of Canada, 1920.

PLATE VI.

GREAT CLUSTER IN HERCULES.

Exposure 60^{m}, Seed 30 Plate. Enlargement 2.8 diam.

Journal of the Royal Astronomical Society of Canada, 1920.

THE JOURNAL
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VOL. XIV JUNE, 1920 No. 5

THE OPTICAL PARTS OF THE 72-INCH TELESCOPE.

BY J. S. PLASKETT

This telescope has already been described in various stages of construction to the readers of this JOURNAL, principally, however, with regard to the mounting, and only general statements in regard to the quality and performance of the optical parts have been given. I propose, therefore, in response to a request from the Editor, to attempt to describe in non-technical language the methods used in testing the quality of the optical surfaces, both during construction and in operation, and it is probably best to preface this description by a short summary of the dimensions already given.

The principal mirror is 73 inches in external diameter, 12 inches thick at the edge, 11.1 inches at the centre and has a central hole 10.1 inches in diameter. The front surface is figured accurately to a paraboloid of revolution with a focal length of 361.3 inches while the back is ground and polished approximately flat. The weight of the finished mirror is approximately 4,340 lbs. The Cassegrain mirror has an external diameter of 19.5 inches and a thickness at the edge of 3.25 inches. Its front surface is a hyperboloid of revolution with a focal length of 118.5 inches and it is placed about 86 inches inside the principal focus of the main mirror, giving an equivalent focal length for the combination of 108 feet. The Newtonian mirror has the same dimensions as the Cassegrain, with an optically flat front surface, the rear surfaces of both mirrors being ground and polished approximately flat. The weight of each is about 80 lbs.

The optical parts of the telescope were ordered from the J. A. Brashear Co., Pittsburgh, in October 1913, and they immediately ordered from the St. Gobain Glass Co. of Paris the discs for the principal and secondary mirrors and also a disc 55 inches in diameter to be used as an auxiliary testing plane. On the second trial the disc for the principal mirror was successfully cast and annealed at the Charleroi works of the St. Gobain Co. and the Brashear Co. were asked whether this disc and those for the secondary mirrors should be shipped or held until the 55-inch disc was completed. Fortunately they decided on immediate shipment and the three discs left Antwerp only about a week before war was declared, arriving in Pittsburgh early in August 1914. The 55-inch disc, if completed, must have suffered destruction at the same time as the factory early in the war.

The main disc when received was about 73.5 inches in diameter, 13 to 13.5 inches thick with a central cored hole, tapered, irregular and slightly eccentric, from 6 to 8 inches in diameter. The weight was nearly 5,000 lbs. Although apparently well annealed the greatest care was used in the rough grinding process, especially around the central hole, to take off the outer skin slowly and to avoid any temperature effects in the grinding, during which about 600 lbs. of glass were removed, the mirror being reduced to the dimensions already given. After rough grinding all over, the back was fine ground and polished approximately flat and the front surface was then fine ground to a spherical surface of radius 720 inches and polished. This polishing of the surfaces, which was completed in August 1915, about a year after the disc was received, showed the material to be remarkably perfect and homogeneous, only at one place near the edge and in the interior extending over a very small area, could a few small bubbles be seen, which were of course absolutely without effect on its optical qualities.

Although apparently identical with the completed mirror, the disc still was useless for optical purposes, still required the most vital part of the process, the figuring. As is well known the figuring consists in a continuation of the polishing process by various sized polishing tools under varying conditions until the final result is achieved. It is in essence a method of cut and try, polish and test the figure, gradually approaching closer and closer until all parts of

the surface will bring an incident parallel axial beam to a focus at one point with the minimum possible aberration. The very nature of this process carries its own evident dangers, for if one part is polished too far the only recourse is to bring all other parts of the surface down to this level, a practical repetition of a considerable part of the process. Consequently, there is required not only a discriminating judgment combined with the highest technical skill and an infinite amount of patience but almost an intuitive instinct, an artistic sixth sense, to guide the optician in his work.

It is evidently essential to have a means of accurately testing the progress of the figuring, of determining the exact form of the surface, in order to know where and how to use the polishing tool. As no mechanical method is sensitive enough for the purpose, this is practically universally effected during the process of figuring by means of what is known as the Foucault or knife edge test. The purpose of every astronomical objective, refracting or reflecting, lens or mirror, is to bring the parallel beam of light from a star to an accurate focus. The knife edge test is applied directly in the beam of light coming from a star, real or artificial, evidently therefore analyses the objective under similar conditions to its practical use in the telescope, and infallibly shows the exact condition of the surface and the parts where work is required. If the lens or mirror under test were pointed at a star and the eye placed close behind the image produced, it would see the whole surface illuminated by the star light. If now a sharp edge, a "knife edge", is brought up laterally across the converging beam from the star just in front of the eye, the surface will be seen to darken, from the approaching side if the knife is within and from the opposite side if without the focus. If exactly at the focus and the surface is accurately figured the darkening will take place uniformly over all the surface. If the figuring is not complete the distribution of light and shade over the surface as the knife edge occults the converging beam indicates to a practiced optician exactly where to continue the polishing to improve the figure. It will be noticed then that the knife edge test enables, first of all, the focus to be accurately determined and this is important to remember in connection with the testing of the 72-inch mirror, and secondly, it shows where polishing is required and gives unmistakeable evidence at completion.

There are, however, grave objections to using star light as the source of a parallel beam. In the first place the testing could only be done on a clear night, with great difficulties in the way of mounting the lens or mirror and pointing at and following the star; in the second place owing to disturbances of the air and temperature differences it would only be very rarely possible for a satisfactory test to be carried out. Consequently, opticians have been compelled to use an artificial star, a strong light behind a pinhole, and some means of making this light into a parallel beam similar to that from a star. This is practically universally accomplished by the use of an accurate plane mirror. The simplest case is in the testing of a lens. If the artificial star be placed at the focus of the lens, evidently the light passing through the lens will be turned into a parallel beam exactly the reverse action to bringing a parallel beam to a focus. The plane mirror behind the lens will reflect back this parallel beam through the lens thus forming an image of the artificial star coincident with or beside the latter, Fig. 1. This artificial star image can then be examined with the knife edge and eye in a constant temperature testing tube at any time and under perfectly steady conditions, with the added advantage that owing to twice passing through the lens any aberrations will be doubled in magnitude and more readily detected. In the case of a parabolic mirror, the plane mirror will have to be placed behind the knife edge so that the light from the star at the focus is reflected back in a parallel beam to the plane mirror, thence again to the parabolic mirror and back to a focus beside the artificial star. Unless there is a hole in the centre of the plane mirror, a third small plane mirror placed at an angle of 45° will be required to place star and observer outside the parallel beam as shown in Figure 1, somewhat similar to the function of the Newtonian mirror in the reflecting telescope.

The largest plane owned by the Brashear Company was only 33 inches in diameter, hence less than half the diameter of the 72-inch could be seen at one time with this plane, giving very inadequate tests. The lack of the 55-inch disc ordered from the St. Gobain Co. for the purpose of making a collimating plane three-fourths the diameter of the 72-inch, held up the figuring for a year. Attempts to get such a disc made in America were failures and

although Director Hale of the Mt. Wilson Observatory kindly offered to loan the 60-inch plane used in figuring the 100-inch mirror, it was in use at Mt. Wilson when needed at Pittsburgh. It was consequently decided, in September 1916, as the mounting was now practically ready, to proceed with the figuring, depending upon tests by another method for determining the general form of the surface and using the 33-inch plane only to test the smoothness of the surface and the freedom from minor zonal irregularities.

This alternative method depends on measuring the radius of curvature of various zones of the paraboloid. A spherical mirror of 72-inches diameter and radius of curvature of 720 inches, which

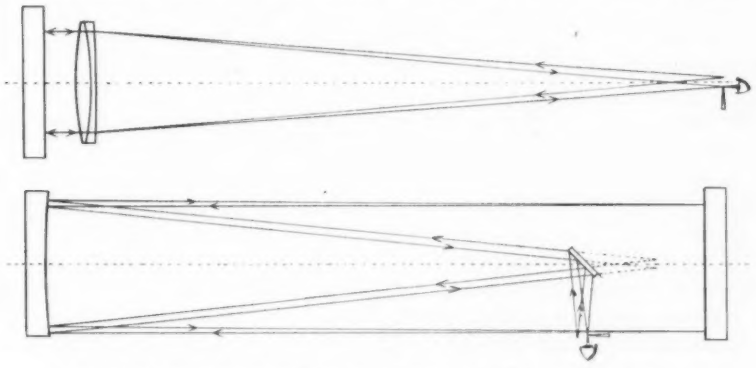


FIG. 1.—METHOD OF MAKING THE FOUCAULT OR KNIFE-EDGE TEST

differs from the paraboloid of the same diameter and 360 inches focus by less than one-thousandth of an inch, could easily be tested by the knife edge as the light from an artificial star at the centre of the sphere would form a real image beside the latter. In the case of the paraboloid of revolution, however, the images of an artificial star for different zones are situated at varying distances from the centre outward or, in other words, the radius of curvature instead of being constant as in the sphere is greater for each zone by the amount that zone is higher than the centre. Thus in the 72-inch the radius for the edge of the mirror is nine-tenths of an inch longer than the radius of the centre just as the edge is nine-tenths of an inch thicker than the centre. The radius of curvature ρ of any zone

of radius R of a paraboloidal mirror of focal length F is given by the equation

$$\rho = 2F + \frac{R^2}{4F} + \frac{R^4}{32F^3}$$

and if an artificial star be placed at a distance $2F$ from the centre of the mirror the intersection or image of the pencil from any zone of radius R will evidently come at a distance of $\frac{R^2}{2F} + \frac{R^4}{16F^3}$ beyond the star.

This property of the paraboloid, and the ease and accuracy with which the focal positions of the intersections of pencils of any zone can be determined by the knife edge, evidently enables the figure to be accurately tested but the interpretation of deviations from the theoretical positions of focus of the different zones and the determination of where work is required on the surface is not nearly so simple and direct as in the knife edge test with parallel light and rendered the figuring a much more difficult process.

A very convenient method of making these radius tests was devised by Dr. Brashear and merits description. The whole surface of the mirror, placed in a vertical position in one end of the testing tube was covered by a paper diaphragm, along the horizontal diameter of which a number of concentric slots about an inch wide and six inches long were cut. These slots were spaced every four inches along the diameter at distances of 35, 31, 27, 23, 19, 15, 11, 7 inches on each side of the centre, thus enabling the radius of curvature of eight zones of the surface to be measured. Each of these zonal slots was covered by a cardboard valve and these valves could be lifted by strings carried back to the centre of curvature, enabling any particular pair corresponding to any desired zone to be uncovered by the measurer at will. This was a decided advantage, in removing confusing effects and trouble of identification of zones, over having all the zones uncovered.

The artificial star was fixed in position near the centre of curvature about 60 feet in front of the mirror and instead of making micrometer measurements of the position of the knife edge situated to one side of the star, the former was fixed on an accurate and easy moving slide to which a short straight edge at right angles to the

movement was attached. A piece of paper or card was pinned under this straight edge and when the position of equal darkening of the pair of exposed slots, corresponding of course to the position of focus for that particular zone, was determined, a line was ruled on the paper by a sharp pencil against the straight edge. When all the zones were measured, there would be eight transverse lines whose positions could be compared with the positions of similar lines ruled on a standard card at the theoretically determined distances. This method enabled the condition of the surface to be determined at a glance, was more direct, simple and rapid than micrometer measures and of practically equal accuracy, the probable error of measurement of the focus of any zone not exceeding about 0.01 inch, equivalent to an aberration of one-fourth that amount, 0.0025 inches, at the principal focus.

Parabolization of the surface was commenced in September 1916, was halted for two or three months by the cold weather and resumed in March 1917. The Brashear Co. had expected to complete the mirror by the spring or early summer of 1917 but unexpected difficulties arose due principally to the presence of the large central hole causing an irregular and unexpected shape of the surface near this opening and to the difficulty in interpreting, by the new method of testing, the shape of the surface and the treatment required. The mirror was nearly finished in August and again in October but in the first case scratches appeared and in the second case the centre was deepened too much, both necessitating repolishing and refiguring. Nevertheless, although the firm were much crowded by important war work, the figuring was persistently continued and, profiting by past experience, was successfully completed on April 3rd, 1918. On March 20th I was summoned to Pittsburgh, as the Brashear Co. were undecided whether to continue the correction or consider the mirror finished. On arrival on March 28th, and carefully testing by measuring visually the radii of the various zones, the outer part was found to be practically perfect but the inner zones were slightly under-corrected, equivalent to a focal length for the central zones about half a millimetre longer than for the outer part of the surface. This small aberration would probably have no sensible effect on the performance but as numerous tests under changing temperature conditions in the testing tube appeared

to show increased deviations, it was decided to reduce the under-correction. Local polishing was continued until April 3rd when the zonal measurements showed no deviation between the measured and computed positions greater than one millimetre, equivalent to a quarter millimetre at the principal focus. Further tests at the principal focus, using the 33-inch plane, showed a smooth regular surface, and the mirror was accepted on the evidence of these tests.

However, as the surface required silvering in order to test the correction of the Cassegrain mirror, it was determined to make confirmatory tests at the centre of curvature of the 72-inch mirror by the Hartmann method of extra-focal exposures. This method is very simple in principle, depending upon the determination of the focal point of any zone from the measures of the distance apart of the images of pencils on plates taken inside and outside the focus. Thus if *CO* and *DO* be two narrow pencils coming from an artificial

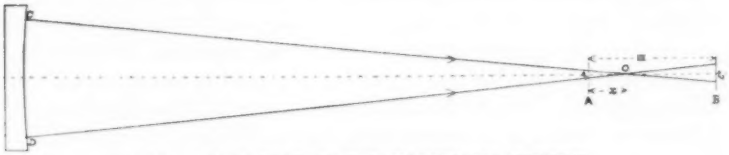


FIG. 2—PRINCIPLE OF THE HARTMANN METHOD

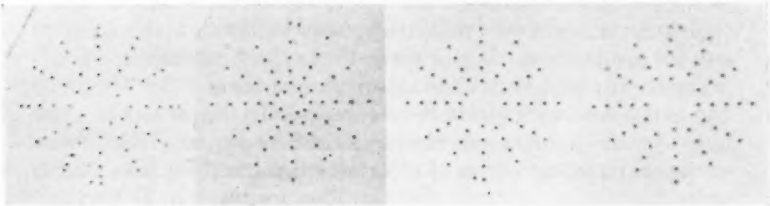
star near *O* and reflected through two small apertures in a diaphragm over the mirror surface at *C* and *D*, it is evident that photographic plates exposed at *A* and *B* will have each two small images on them, the distance apart of these images depending on the distance of the plates from the intersection or focus *O*. From similar triangles we at once have if r_1 and r_2 be the distance apart of the images on the plates *A* and *B*

$$\frac{r_1}{x} = \frac{r_2}{a-x} \text{ or } x = \frac{ar_1}{r_1+r_2}$$

It is evident that by properly spacing circular apertures in a paper diaphragm we can determine the intersection points of as many zones as we please at one time. To determine the figure of the 72-inch mirror by this method a diaphragm of stiff paper of sufficient size to cover the whole surface was stretched over a light frame and 60 circular holes each about 1.5 inches in diameter were

cut in this diaphragm. These holes were spaced along six diameters of the mirror 30 degrees apart, 10 holes in each diameter and were so arranged that on each of 15 zones of the mirror, of 7, 9, 11 .... 33, 35 inches radius, were four holes of two diameters 90° apart. Hence the intersection point or focus of each zone is determined along two diameters and not only the zonal aberration but the astigmatism is obtained. The extra-focal images *a* and *b*, Fig. 3, taken at the principal focus give a good representation of the spacing of the holes in the diaphragm. Such a method can evidently equally well be used at the principal focus of the telescope by using a bright star or at the centre of curvature in the testing tube using an artificial star.

Consequently, in the testing tube at Pittsburgh an artificial star formed by an acetylene flame and a small pinhole was fixed



a b c d

FIG. 3—EXTRA-FOCAL IMAGES

in position slightly to one side of the centre of curvature of the mirror, which was covered by the perforated zone plate above described, and a plate holder carrying plates 2 by 3 inches and held in a sliding frame was placed on the other side in a position to intercept the reflected pencil from the mirror. A reproduction of two of the images is given in Fig. 3, *c* inside focus, *d* outside focus. Owing to the spacing of the intersections of the various zones over a distance of about 1.6 inches along the axis the images of the holes in the diaphragm are differently distributed in these two plates, crowded together at the centre for the plate inside the focus and towards the edge for the plate beyond the focus. The separation of these two plates was about 12 inches, much greater, owing to the smaller convergence of the pencils and the unsymmetrical distribu-

tion, than in the less than 3 inches separation required in plates made at the principal focus of the telescope.

After silvering, the mirror stood 28 hours, when the first series of plates was made in the evening hours, but to make sure the mirror was in a steady state, the earlier exposures having been made just after the apparatus was set up, another series was made next morning after the tube and mirror had been undisturbed for 10 hours. The exposures were made on Seed 23 and Process plates and six plates, three on each side of the focus were measured on the micrometer microscope of the Allegheny Observatory. The agreement of the separate measures was excellent, showing the reliability of the method, and this taken in conjunction with the good agreement between these and the earlier visual measures shows that we have an accurate picture of the form of the surface. In Table I the results of these measures are given, the first two columns containing the measured distances between the separate pairs of apertures in the zone plate, the angles between corresponding pairs in the first and second quadrants being 90°. The third and fourth columns contain the theoretical distance in inches, computed by the formula previously given, between an artificial star at the centre of curvature of a perfect mirror and the intersection or focus of the pencils from the corresponding zone in the first and second columns. The fifth and sixth columns contains the meaured distances as derived by the Hartmann method, the zero point of

TABLE I—ZONAL ABERRATIONS OF 72-INCH MIRROR.

Separation of Apertures in Zone Plate.		Computed Focal Distances.		Measured Focal Distances.		Residuals O-C.		Mean Zonal Difference.	Aberration at Focus.
1st Quad.	2nd Quad.	1st Quad.	2nd Quad.	1st Quad.	2nd Quad.	1st Quad.	2nd Quad.	Inches.	Millimetres.
70.10	70.12	1.702	1.703	1.689	1.680	−.013	−.023	−.018	−0.11
66.14	66.16	1.515	1.516	1.539	1.499	+.024	−.017	+.003	+ .02
62.04	62.16	1.332	1.338	1.394	1.262	+.062	−.076	−.007	− .04
58.12	57.98	1.160	1.164	1.152	1.129	−.017	−.035	−.026	− .16
54.00	54.10	1.011	1.015	1.026	.983	+.015	−.032	−.008	− .05
50.13	50.00	.870	.865	.884	.821	+.014	−.044	−.015	− .09
46.12	46.01	.736	.732	.743	.730	+.007	−.002	+.002	+ .01
42.09	41.98	.613	.610	.644	.596	+.031	−.014	+.008	+ .05
38.00	38.00	.499	.499	.563	.513	+.064	−.014	+.039	+ .24
34.12	34.12	.403	.403	.463	.405	+.060	+.002	+.031	+ .19
29.96	30.06	.310	.312	.328	.295	+.016	−.017	.000	.00
25.94	26.24	.232	.238	.272	.215	+.040	−.023	+.008	+ .05
22.06	22.00	.166	.167	.211	.145	+.045	−.022	+.011	+ .07
18.12	17.96	.114	.111	.126	−.050	.....	.....	.....	.....
13.93	14.12	.067	.069	−.024	−.054	.....	.....	.....	.....

the scale corresponding to the weighted mean position of best focus. The seventh and eighth columns contain the residuals between the observed and computed positions, the ninth column giving the mean while the tenth column gives the aberration at the principal focus of the mirror in millimetres.

The last column gives the mean measured longitudal aberration in millimetres at the principal focus of the mirror, that is, when used with parallel light. The mean deviations, given in the ninth column, of the focus of different zones at the centre of curvature when the artificial star is fixed are of course four times as great. These means are obtained from the seventh and eighth columns, giving the actual deviations, along two diameters 90° apart, from the theoretical computed positions, thus giving a measure of the astigmatism. The diaphragm was so placed over the mirror that the one set of zonal openings corresponding to what is called the first quadrant were all situated within 30 degrees of the vertical and the other, the 2nd quadrant, within 30 degrees of the horizontal. Unfortunately no thermometers were available to determine the temperatures in the testing tube but as it was only two or three inches wider and higher than the mirror, there was likely considerable stratification in horizontal layers cooler at the bottom, warmer at the top. The measures indicate some astigmatism equivalent to about a quarter millimetre at the principal focus, but this must be almost wholly a temperature effect as it practically disappears in the later measures made when the mirror is in place in the telescope. Indeed it is impossible to imagine there could be any permanent astigmatism when the tremendous amount of polishing with a full sized tool required to remove scratches inadvertently obtained at two stages of the figuring is considered.

The mean values of the aberration in the last column may then be taken as representing the condition of the surface. These aberrations are remarkably small, the maximum 0.24 mm. for a zone of 19 inches radius, and the mean less than 0.1 mm. The maximum deviation of 0.24 mm. is equivalent to a deviation of the surface of about one-eighth of a wave length of light, a very close approach to theoretical perfection. This accuracy is several times within the aberrations produced by changing temperature or by unsteadiness of the seeing and the mirror may be considered practically perfect.

It was decided as soon as the mirror was installed in the telescope to make additional Hartmann tests in order to determine the effect of the inevitably changing temperature conditions on the form of the surface. The extra-focal plates were easily and quickly obtained, all that was necessary being to place the same zone plate as was used in Pittsburgh over the mirror, to point the telescope to a bright star and with the double slide plate holder which has a focussing range of about six inches make one exposure from an inch to an inch and a half inside the focus and a second one the same distance outside. Exposures of 5 to 10 seconds on Vega or 30 seconds on a second magnitude star suffice to give good extra-focal images on fine grained plates and a set can be obtained in a few minutes. The measures of the plates in this case give at once the residual zonal aberrations at the principal focus without the comparisons with computed positions and reductions necessary when the test was made at the centre of curvature.

Two nights were chosen, shortly after the mirror was installed, on May 12th, 1918, when the temperature varied over a range somewhat greater than the average and on May 19th, when the variation was about the minimum. On May 12th the dome temperature had gradually risen from 52° F. at 6 a.m. to a maximum of 62° at 6 p.m. and, when the dome was opened at 8.15, the temperature had fallen to 60°.8. At 9.10 when the first set of plates was made, the dome temperature was 56°.9 and at 11.30 when the second set was obtained the temperature had fallen to 54°.9. On May 19th the dome temperature, over 18 hours between midnight and 6 p.m., varied less than a degree, from 55°.7 to 56°.6. At 8.20 p.m. when the first set was made, the temperature was 54°.4 and at 8.30 for the second set 54°.0. The third set was made at 10.00 with temperature 53°.9, the fourth at 11.00 temperature 53°.3, the fifth at 1 a.m. temperature 52°.4, and the sixth at 3 a.m. temperature 52°.1. The results of the measures of these plates are given in Tables II and III and are shown graphically in Fig. 4 (p. 194.)

The results of these tests are worth noting, in the first place because they show that the astigmatism indicated in the shop test is no longer present, especially on May 19th when the temperature change has been very small. Here the differences in focus for quadrants 1 and 2 are not only very small but occur in such an

TABLE II—ZONAL TESTS MAY 12

Radius of Zone	Exposure 1			Exposure 2			Differences of Focus	
	Focus Quad. 1	Focus Quad. 2	Mean Focus	Focus Quad. 1	Focus Quad. 2	Mean Focus	Exp. 1	Exp. 2
in.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
35	45.75	45.81	45.78	43.23	43.44	43.33	0.00	0.00
33	46.26	45.74	46.00	44.03	43.50	43.76	.22	.43
31	46.08	46.34	46.21	43.87	43.96	43.81	.43	.48
29	46.81	46.42	46.61	44.06	43.83	43.94	.83	.61
27	46.84	46.75	46.80	44.51	44.18	44.34	1.02	1.01
25	46.87	47.52	47.20	44.51	44.77	44.64	1.42	1.31
23	47.68	47.11	47.40	45.11	44.84	44.97	1.62	1.64
21	48.05	47.03	47.54	44.98	44.98	44.98	1.76	1.65
19	47.41	48.04	47.72	45.02	45.35	45.18	1.94	1.85
17	48.02	47.48	47.75	45.56	45.00	45.28	1.97	1.95
15	47.92	48.07	47.99	45.09	45.27	45.18	2.21	1.85
13	47.94	48.83	48.23	44.52	46.05	45.28	2.45	1.95
11	49.79	48 92	49.35	46.55	45.21	45.88	3.57	2.55

TABLE III—ZONAL TESTS MAY 19

Radius of Zone	Foci at Exposure 2			Mean Foci at Exposures			Differences of Focus at Exposures			
	Quad. 1	Quad. 2	Mean	3	5	6	2	3	5	6
in.	mm.	mm.								
35	44.11	43.89	4.00	3.65	3.09	2.93	0.00	0.00	0.00	0.00
33	44.50	44.74	4.62	4.08	3.52	3.51	.62	.43	.43	.58
31	44.52	44.45	4.48	4.07	3.54	3.33	.48	.42	.45	.40
29	44.30	44.41	4.36	3.82	3.31	3.07	.36	.17	.22	.14
27	44.61	44.57	4.59	4.04	3.30	3.00	.59	.39	.21	.07
25	44.74	44.54	4.64	3.90	3.35	3.05	.64	.25	.26	.12
23	44.67	44.73	4.70	4.17	3.60	3.33	.70	.52	.51	.40
21	44.99	44.64	4.81	4.25	3.34	3.26	.81	.60	.25	.33
19	44.97	44.82	4.89	4.25	3.51	3.25	.89	.60	.42	.32
17	44.80	44.54	4.67	4.07	3.48	3.13	.67	.42	.39	.20
15	44.98	44.47	4.67	4.00	3.44	2.91	.67	.35	.35	− .02
13	45.03	44.29	4.66	3.91	3.36	2.96	.66	.26	.27	+ .03
11	44.69	44.66	4.67	3.80	3.15	2.13	.67	.15	.06	− .80

irregular fashion as to indicate that the differences are likely in the nature of accidental errors and that there is certainly no permanent astigmatism present in the mirror. In the second place the main result derived from these tests is the evidence of the great effect of temperature changes on the form of the surface. Owing to temperature lag in the telescope tube around the mirror and in the mirror itself, it is probable that the resultant under-corrected figure, focus at centre over 3 mm. longer than focus at edge, of the first exposure on May 12th, is due to the gradually rising temperature during the day. At the second exposure 140 minutes later the effect of decreasing temperature has begun to show and the positive aberration, under-correction, is slightly reduced. The same thing is shown in the exposures on May 19th as during decreasing temperature between exposures 2 and 6 the focal length of the centre is con-

tinually decreasing with respect to the edge. Another evident effect is the action on the outer zone which is the exact opposite of what would naturally be expected. Owing to the exposure of the edge of the mirror as well as the front to the decreasing temperature it would be supposed that the edge would roll back; instead of that it quite markedly curls up. This is evident by the considerably shorter focal length of the zone of 35 inches radius, one inch from the edge, than of the adjacent zones which persists through all the tests. The general change in the figure due to exposure to the night sky both on May 12th and May 19th is, however, relatively small, probably due to the bright silver surface preventing radiation, and it appears if the daily rise of temperature around the mirror could be diminished, the working figure would be improved.

The result of the tests then was taken as indicating the necessity of some device, such as the "canopy" used on the Mt. Wilson 60-inch reflector, to diminish the rise of temperature around the mirror during the daylight hours. Considerable thought was given to the best method of accomplishing this. The arrangement of mounting and dome made a suspended canopy impracticable and it was at first planned to make a box in two halves with refrigerator walls, mounted on casters to be rolled up to the tube placed in the vertical position, encircling it and covered over at the top of the closed section by a removable pad of blankets. But these two sections would be unsightly, bulky, cumbersome and difficult to get out of the way when observing.

The plan of placing a permanent insulating cover entirely surrounding the lower closed section of the tube containing the mirror was finally decided on and the encasing of the mirror was made complete by similar permanently placed insulating material at the bottom of the cell and a removable pad of woollen blankets placed on light boards laid over the top of the closed section of the tube. In addition, insulating felt was packed all around the edge and bottom of the mirror so that radiation could only take place from the silvered surface and this, owing to the polish, would be very slow.

The insulating material employed was the cotton felt used in making mattresses. The conductivity of this felt is not much greater than wool and its cost is less than one-fourth. Quilted pads

about two inches thick covered with heavy cotton were made of this material and the outer cylindrical sections of the cell and central section of the tube were covered from top to bottom. These pads were covered with a close-fitting cover of khaki-covered duck laced tightly over the padding, making a permanent and neat-looking job. These pads and covering can be seen in Plate III which shows the telescope arranged for direct photography at the Newtonian focus. Similar pads were placed directly above the circular metal plates covering the bottom of the cell and the space between these pads and the mirror was completely filled in with the felt. Similarly around the edge of the mirror, between it and the cell, pads of the felt were placed above the counterpoise ring extending up to the very edge of the surface, while below these pads the space between cell and mirror was completely filled in with the loose cotton.

The mirror and closed section of the tube were now completely encased in insulating material with the exception of the top which, during observing, must of course be open to the sky. As previously stated, this was covered during the day by a removable pad of three thicknesses of the best woollen blankets laid on light boards placed across the top of the central section.

There is hence enclosed within this protective covering 12 tons of steel and 2 tons of glass and the quantity of heat stored there makes the change of temperature within the insulator very slow. Tests with a thermograph inside have shown that in general the change of temperature around the mirror is only about one-third that in the dome. In practice, as the cover is put on as soon as observing is finished in the morning, slightly above the minimum temperature reached during the night, and as the range inside is about one-third of that in the dome, the mirror is hence, when the dome is opened, usually from 2° to 3° F. below the temperature at the beginning of observing. As the average fall from then until dawn is about 5° F., it is evident that there is never any high temperature gradient between the mirror and the surrounding air, that all except the slowly radiating upper surface is protected by felt and that hence the changes in figure will be slow.

Practical experience has shown that the performance is much improved and that the aberration present in the mirror is generally negligible. Hartmann tests have only been made on two nights

since the covers were applied. On September 26th, 1918, the general temperature, interrupted of course by the usual daily increase and decrease, had been gradually rising from 52° F. on Tuesday, September 24th at 6 a.m. to 58° on Thursday, September 26th at 6 a.m. Both Tuesday and Wednesday had been cloudy and when the sun came out on Thursday morning the temperature in the dome rose from 58° at 6 a.m. to 71°.4 at 5 p.m., an unusually large change and a much severer test on the figure than it is normally exposed to. A thermograph placed inside the tube near the mirror had risen from 55° F. on Tuesday at 6 a.m. to 62° F. on Thursday at 7 p.m. when the dome was opened. On being placed outside the tube in the dome it immediately rose 6° showing that the dome temperature was about 6° above that of the mirror. Nevertheless the previous change around the mirror had been slow and, even with this great difference the protection of the felt around edges and bottom and of the silver on the top seemed to keep the change gradual enough to prevent much distortion. Table IV, which contains the result of two Hartmann tests on this date, the first one hour, the second two and a half hours, after the mirror was open to the sky, shows that the aberration even under these unusually severe conditions is quite moderate, less than one-half that on the unprotected mirror on May 12th with a much smaller change of temperature, and that the mirror has a good working figure.

Similarly on April 29th, 1919, another Hartmann test was made at the principal focus. In this case the temperature during the early morning hours from 3 a.m. to 7 a.m. had been practically constant at 48°.5 F. The insulating cover was not placed over the top until about 10 a.m., when the temperature had risen to 53° F. The mirror was opened to the sky at 9 a.m. to test the collimation of the secondary when the temperature was at 52°.3 and closed and covered at 10 a.m. From then until 6 p.m. the temperature gradually increased to 57°.5 when the dome was opened. When the mirror was uncovered at 7 p.m. the dome temperature was 55.5, at 8 p.m. 54°.0, at 9 p.m. 53°.8, and from 10 p.m. until 1 a.m. remained practically constant around 53°.0. Hartmann tests were made at the Cassegrain focus between 9.35 and 10.15 and at the prime focus between 12 and 12.45 The results of the latter, also given in Table IV, show a very good working figure.

TABLE IV—ZONAL TESTS SEPTEMBER 26, 1918, AND APRIL 29, 1919.
FOCI IN MILLIMETRES.

Radius of Zone	Sept. 26, 1918 Foci at Exposure 1			Exp. 2	Foci on April 29, 1919			Differences of Focus		
	Quad. 1	Quad. 2	Mean	Mean	Quad. 1	Quad. 2	Mean	Sept. 26, 1	Sept. 26, 2	Apr. 29
in.										
35	33.52	33.90	33.71	33.90	29.80	29.96	29.88	0.00	0.00	0.00
33	33.69	33.82	33.75	34.02	30.45	30.16	30.30	0.04	0.12	0.42
31	33.82	33.41	33.61	33.92	30.34	30.18	30.26	−0.10	0.02	0.38
29	33.59	33.68	33.63	33.70	29.83	30.34	30.08	−0.08	−0.20	0.20
27	33.64	33.74	33.69	34.10	30.22	30.25	30.23	−0.02	+0.20	0.35
25	33.90	34.34	34.12	34.28	30.49	30.39	30.44	+0.41	0.38	0.56
23	34.23	34.01	34.12	34.57	30.28	30.82	30.55	0.41	0.67	0.67
21	34.09	34.16	34.12	34.67	30.34	30.66	30.50	0.41	0.77	0.62
19	34.69	34.60	34.64	34.92	31.19	30.79	30.99	0.93	1.02	1.11
17	34.51	34.89	34.70	35.10	30.49	31.03	30.76	0.99	1.20	0.88
15	34.85	34.76	34.80	35.04	30.71	31.09	30.90	1.09	1.14	1.02
13	35.61	34.15	34.88	35.63	31.24	30.95	31.09	1.17	1.73	1.21
11	35.58	35.81	35.69	36.54	30.80	31.84	31.32	1.98	2.64	1.44

The results of all these tests are shown graphically in Fig. 4, where the ordinates represent the positions of focus in millimetres of the various zones shown as abscissae, the edge of the mirror being at the left. The straight horizontal line at each curve represents the weighted mean position of best focus, taking account of the relative areas of the different zones. Distances from the curve to this line represent deviations from the mean focus, longitudinal aberrations, above the line longer, below shorter focus. The cross sectional parts at the bottom represent the relative positions of principal and Cassegrain mirrors.

The change from the shop test at constant temperature to that of May 12th where the temperature change was above the average is very marked as also the great improvement when the change was very small on May 19th. That the introduction of the insulated covering has markedly improved the general figure is evident by a comparison of the curves on May 12th before, and September 26th and April 29th after the cover was applied. Not only is the total longitudinal aberration after less than half that before, but from the edge to a zone of radius 21 inches, three-fourths the area of the surface and of even relatively greater importance in the size of the image on account of the greater convergency of the pencils, the aberration is only one-third of the amount before insulation. The general effect of the temperature changes occurring in actual observing practice seems to be towards under-correction, the edge curls up and the focus at the centre is longer than that

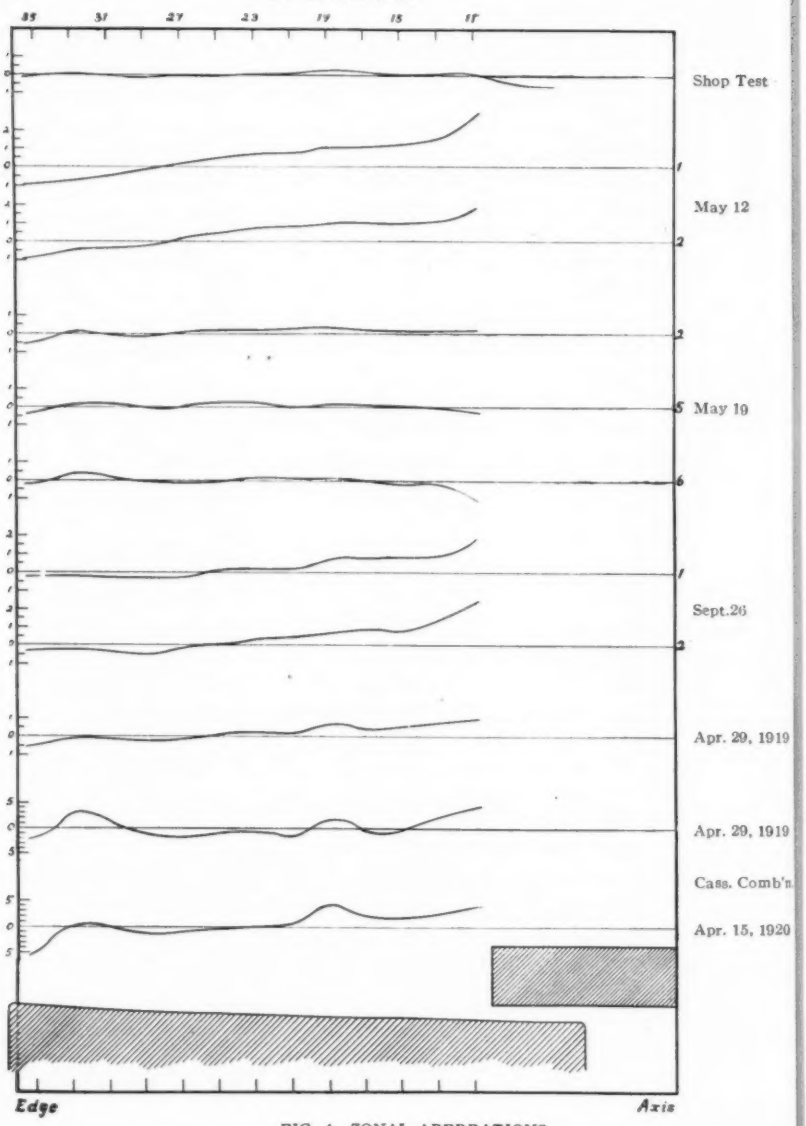


FIG. 4—ZONAL ABERRATIONS

at the edge. So far as actual practical efficiency goes it would therefore seem to be advisable to over-correct a parabolic mirror slightly, even roll back the edge somewhat, to give better average conditions of figure, but it would be difficult to say to how great an extent to carry this and probably most astronomers and opticians will prefer to have the surface theoretically correct under constant temperature.

The telescope has not yet been much used at the principal focus and only a few direct photographs have been obtained but these few, some examples of which are seen in Plates IV-VI, have been sufficient to show that, when the seeing is good, the star images are very small and sharp, the minimum diameter being only slightly over one second of arc. This taken in conjunction with the direct tests is sufficient to show the practical perfection of the figure.

The telescope, however, is much more often used in the Cassegrain form and hence the figure of the Cassegrain mirror is equally important with that of the principal mirror. It is evident that the figure of the Cassegrain can only be tested in combination with the principal mirror as the light falling on it is a converging pencil from the latter. Although the Cassegrain was fine ground to the correct radius of 237 inches and polished, no figuring could be done until the 72-inch mirror was finished. Again tests at the centre of curvature are impossible as the surface is convex and no real focus can be obtained. It was, therefore, necessary to test with the knife edge at the focus of the combination in parallel light, and, as only the 33-inch plane was available, only half the surface could be seen and tested at one time. The 72-inch mirror was placed in its usual vertical position in the testing tube and the Cassegrain was placed facing it at the computed distance. Beyond the Cassegrain, the 33-inch plane was set up and adjusted parallel to the 72-inch but to one side so that it was intermediate in position between adjacent edges of 72-inch and Cassegrain. The artificial star was placed about 18 inches behind the 72-inch, in the same relative position as the spectrograph slit in the telescope, and the knife edge beside it. Light from the artificial star at the focus of the combination, passes through the central hole to the Cassegrain and is reflected thence to the 72-inch. It evidently is reflected from the latter in a parallel pencil to the plane and again back in a parallel pencil

to the 72-inch, thence to the Cassegrain and from there to a focus beside the knife edge. The figure of the combination can only be seen along one horizontal radius and the interpretation of the shadow effect and of the form of the surface is difficult as it is usual to compare the shadows along the whole diameter. However, Mr. McDowell's experience stood him in good stead and the figuring of the Cassegrain was carried in about a week to a condition where it was impossible to tell from the available testing method whether or not more work was required. However, I had no hesitation in accepting this surface as it was certainly good, and because a clause in the contract provided for the Cassegrain being refigured at Victoria if found necessary. It was evidently impossible to test the combination by the Hartmann method at Pittsburgh as this requires the use of the whole surface and a definite quantitative test was therefore postponed until the full sized parallel pencil from a star could be used on the completed telescope.

However, the definition given by the combination appeared so good and the exposure times on star spectra so short that press of other work caused the postponement of Hartmann tests on the Cassegrain until January 1919. The same zone plate was placed over the principal mirror, the telescope turned to α Persei, then not far from the zenith, and exposures made on small plates near the secondary focus inside and outside focus as before. The separation required in this case owing to the 3.6 times greater focal length and consequently smaller convergency of the pencils was about six times that at the principal focus. The zonal images were much larger and more diffuse, due probably to the linear increase in focal length and the consequently increased diffractional spread. It is probable if the circular apertures in the zone plate were made larger in diameter this diffuseness would be reduced. However, the plates were well measurable and the two sets of measures on January 6th and other two sets of April 29th showed fair inter-agreement as is evident from the measures in Table V, which give in millimetres the positions of focus for the various zones of the combination.

It can be seen from the curve of the combination on April 29th, 1919, in Fig. 4 that the zonal deviations of the main mirror, the turned up or shorter focus edge and the longer focus hump at the

TABLE V—ZONAL DIFFERENCES OF FOCUS OF CASSEGRAIN COMBINATION

	January 6			April 29			Aberrations Prin. Mirror Apr. 29	April 15, 1920		
	1	2	Mean	1	2	Mean		1	2	Mean
35	9.18	10.35	9.76	1.13	1.65	1.39	0.00	1.18	1.39	1.28
33	10.11	13.70	11.90	5.85	6.73	6.29	0.42	7.23	6.32	6.78
31	8.76	11.67	10.21	4.41	4.59	4.50	0.38	6.48	6.79	6.64
29	7.45	10.40	8.92	1.87	2.02	1.94	0.20	4.96	4.89	4.92
27	7.13	10.07	8.60	1.10	1.50	1.30	0.35	5.18	5.98	5.58
25	8.27	11.20	9.73	2.04	2.58	2.31	0.56	5.89	6.18	6.04
23	9.69	12.67	11.18	2.68	2.51	2.59	0.67	6.50	6.81	6.66
21	9.58	12.86	11.22	1.46	2.15	1.80	0.62	6.26	7.74	7.00
19	11.67	14.87	13.27	4.63	5.33	4.98	1.11	10.49	10.94	10.72
17	11.53	15.11	13.32	2.44	3.19	2.81	0.88	8.50	8.62	8.56
15	13.25	16.50	14.87	2.04	3.91	2.97	1.02	8.15	9.90	9.02
13	13.93	17.77	15.85	5.87	5.03	5.45	1.21	8.76	9.25	9.00
11	15.12	21.26	18.19	8.27	6.28	7.27	1.44	10.13	10.58	10.36

19 inch zone are reproduced and intensified by the Cassagrain in even greater ratio, as is to be expected from the small size of the secondary, than the difference in focal length. But other deviations such as the long focus hump at zones of 33 and 31 inches radius must evidently be principally due to incomplete figuring of the Cassagrain. Although these deviations are not relatively great and although the performance of the combination as judged by the visual definition and by the shortness of exposure with the spectrograph is excellent, it was deemed desirable under the provision in the contract enabling the work to be done without additional charge, to have the secondary refigured. On showing these curves to Mr. McDowell in May 1919, he expressed his belief that the figure could be improved and his willingness to combine a holiday trip to Victoria with the refiguring. He arrived here in early August with the necessary polishing tools and material. The knife edge test could be readily applied to the combination without removing the spectrograph by using the visual observing telescope which, attached above the focus to the frame of the spectrograph, turns the converging pencil at right angles by means of a reflecting prism while a symmetrical triplet in the centre of this telescope transfers the image to the outer end where it can be viewed by the ocular or intercepted by a knife edge. Visual tests on a fourth magnitude star with the knife edge showed a figure similar to that given by the Hartmann method and a few moments examination sufficed to tell Mr. McDowell where the surfaces required working. The mirror was worked three times only on two nights with evident

great improvement to the figure. A final test was made on the next night when seeing conditions were good and it was decided, as any deviation from correctness was imperceptible and masked by imperfect steadiness and aberrations due to changing temperature, that it would be unwise to attempt any further correction. Visual tests by the knife edge were made on several other nights, when the temperature and seeing conditions were favourable, all confirming the practical perfection of the figure.

However, owing to various circumstances, a Hartmann test of the refigured combination was deferred until April 15th, 1920 when, under fairly favourable temperature conditions, change of less than 5° F., a test was made of the combination in the same manner as before. Measures of the plates gave the values in Table V, shown graphically in the lowest curve in Fig. 4. An inspection of the table and curve shows that considerable improvement was effected by the refiguring, the curve being considerably smoother and the hump at zones 33 and 31 inches radius being practically entirely reduced. The short focus edge, the long focus hump at 19 inches radius, and the gradually increasing focal length towards the centre are evidently due almost entirely to the principal mirror, as they all appear in the tests made at Victoria under changing temperature conditions. The scale of the curves from the combination is reduced 3.6 times the ratio of the focal lengths, so as to make them directly comparable with the curves from the principal mirror. Although the turned up edge and the irregularity at 19 inches radius are intensified by the Cassegrain, as is to be expected on account of the much smaller size of this surface, the general figure is very satisfactory, the deviations over three-fourths of the area being negligible and almost entirely due to temperature changes in the principal mirror.

The actual performance of the combination is excellent. When the seeing is good the visual star image at the 108 feet focus seen in the spectrograph guiding telescope, power 1,600, is very small and condensed and frequently almost entirely disappears within the slit which is 0″.3 wide. The exposures required are relatively short as a star of type *F* to *K* of 7.0 photographic magnitude will give a well measurable spectrum with a dispersion of 29A to the millimetre at Hγ in 20 minutes. *B* and *A* type stars of the same

photographic magnitude are generally given somewhat longer exposures in order to narrow some of the diffuse lines in these types.

The tests of both principal and secondary mirrors have convincingly shown that the residual errors present under constant temperature conditions are not only absolutely very small but as compared with those produced by even the minimum change in temperature occurring under actual working conditions, to say nothing of the effects of atmospheric disturbances, they are entirely insignificant and without effect on the optical performance of the telescope.

The Brashear Co. are to be congratulated on producing such fine surfaces under such trying conditions and it is only right that I should express my appreciation of their successfu' efforts. The presence of the hole in the centre doubled, according to their estimate, both the difficulties and the time of figuring. Towards the last, the tremendous pressure of war orders coupled with the difficulty of getting optical glass to fill them, and the uncertainty as to the time required for completion, made the figuring, always a nervous strain, doubly trying. I am glad to take this opportunity of expressing my appreciation of their persistence until crowned with such notable success. Dr. Brashear himself, though not of late taking an active part in the optical work of the firm, was much interested in this surface and not only prepared the tools but rough and fine ground and polished the mirror. Many of the methods of handling and testing are due to his ingenuity. The burden of the figuring was, however, taken by Mr. McDowell, the secretary and manager of the company, ably assisted by his chief optician Mr. Fred Hagemann. It was due to their skill and persistence in the face of difficulties and discouragements that the surface was finally brought to such a satisfactory finish. After their experience and success with such a large and difficult undertaking there need be no uncertainty as to the outcome and quality of any optical work entrusted to them.

Dominion Astrophysical Observatory,
Victoria, B.C.,
April, 1920.

DR. JOHN A. BRASHEAR

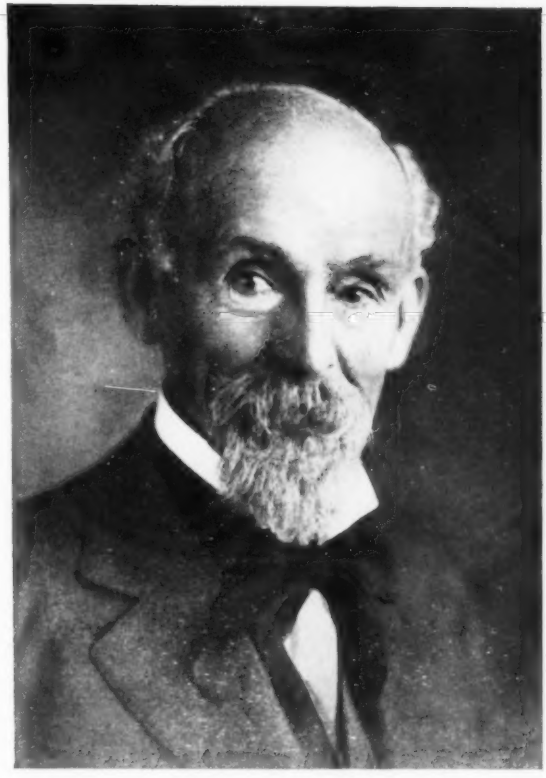
By Frank C. Jordan

The esteem in which "Uncle John" Brashear was held by the people of Pittsburgh was never better manifested than at the time of his funeral on Sunday afternoon, April 11, 1920, when his body lay in state in the Soldiers' Memorial Hall, and thousands from all walks of life, the high and the low, rich and poor, old and young, passed in line before the casket to take a last look at his kindly face, and other thousands crowded the hall to listen to the simple funeral services conducted by Dr. Bonsall, a life-long friend of Dr. Brashear.

He was a man who, rising from the rank of a worker in an iron mill, had made for himself such a place in the world of science, and better still, in the hearts of his fellow beings, that the governor of the Commonwealth of Pennsylvania had bestowed upon him the proud title of the foremost citizen of the state. Many a man has become a noted scientist, and yet has made no name for himself among the rank and file of humanity because he has held himself aloof from them. Dr. Brashear was just the opposite of this. While known throughout the world for his skill in producing astronomical instruments, he was just as happy, perhaps more so, in talking to boys and girls, prisoners in the penitentiary, or others who were absolutely ignorant of Astronomy, as in giving a lecture before a body of scientists.

Besides sending out to the four corners of the world instruments that were the last word in refinement and accuracy beyond the conception of the ordinary person, he felt that, like the apostles of old who had the commission to go into all the world and preach the gospel to every people, he also had a commission to go into the highways and byways, and take to the common people the knowledge of the stars. He spared neither time nor energy in fulfilling this commission. In fact he went out sometimes at the expense of his health.

PLATE VII.



Born Nov. 24, 1840; Died April 9, 1920.

Journal of the Royal Astronomical Society of Canada, 1920.

To his almost unaided efforts is due the raising of a fund of nearly $300,000 for the building and equipment of the New Allegheny Observatory. While a young man struggling to gain a knowledge of the stars, he made a resolution that if he ever had the opportunity he would have a place where all the people who loved the stars could enjoy them. This is similar to the resolution of Andrew Carnegie, that if it were ever possible he would bring books within the reach of everybody. Therefore, while obtaining the funds for the building, Dr. Brashear always kept in mind, not only the scientific work which is the function of an observatory, but also its usefulness to the general public. In pursuance of this latter idea the observatory has one department devoted to the free use of the public. A fine lecture hall furnished by the generosity of a citizen of Pittsburgh, and the old thirteen-inch refractor, which in the hands of Langley and Keeler, made such notable additions to astronomical knowledge, are for the use of the public. A fund provided by Mr. Henry C. Frick provides the income by which Mr. W. R. Ludewig, an enthusiastic amateur, is always on hand on visitors' nights to take charge. All who apply for admission are accommodated. Last year 4,200 visitors availed themselves of the privilege, and this year bids fair to equal or even surpass this record. This early desire of Dr. Brashear is thus abundantly fulfilled. His attitude towards the world is best expressed by the answer he gave when asked what degree he would like to have from a university: "I would prefer to have the title 'Doctor of Humanity'." This explains the place he held in the affections of his fellow beings.

Born of poor parents, he was compelled at the age of sixteen years to give up school and begin to earn his own living, becoming a pattern maker and engine builder. Later he became an iron worker in a Pittsburgh mill. With all this work he had a hobby, and that was the study of the stars, his interest in which dates from the time when as a small boy he had a look through a small telescope. His spare time was occupied in the study of the stars, and imparting his information to his fellow workmen. He was what we call a self-educated man. In the final analysis all persons are self-educated, but some have the advantage of the acquisition of an education directed by a college or university. It is true that

many even with this directive influence have come out from colleges poorly educated, while many others, like Dr. Brashear, lacking these advantages, become well educated persons. He early became possessed with an intense desire to know more of the stars. Too poor to buy a suitable telescope, he took up the task of making one for himself. We are here reminded of the parallel case of Sir William Herschel, who began by constructing a reflecting telescope when too poor to buy one, and ended by becoming the master telescope maker of his time, while at the same time he became one of the greatest observing astronomers of all time. We can imagine the feelings of the iron worker, as after three years' work he went over to the Allegheny Observatory with his first five-inch lens to submit it to the inspection of S. P. Langley, and to receive some direction as to the proper line of work to be undertaken with it. It passed the test, and Langley found he had an optician at hand to whom he could give a commission for work which formerly had to be sent to other places, even across the sea. He built a small shop and spent his spare time in grinding lenses, or doing work on other astronomical instruments. But the call of Astronomy came so strong upon him, that after a trying time in deciding whether to give up a certain income with a limited time for optical work, or launch out for himself in the work he loved without regard to its financial rewards, he chose the latter course, and as all know, became what many consider the master instrument maker of the world. The counsel of a devoted wife to whom he never failed to give much of the credit for his success in life led him to take this step. It was for a long time a hard struggle, but friends like William Thaw came to his aid, and the scientific world was made the richer by the splendid instruments which were the result of his genius. Langley, in his solar studies, profited by his skill; Keeler made his brilliant discovery of the structure of Saturn's rings with a Brashear spectrograph; Michelson depended upon him for optical surfaces of almost incredible accuracy; Max Wolf, of Heidelberg, and Barnard, of the Yerkes Observatory, came to the Brashear Company for large doublets with which to study the structure of the Milky Way; the Allegheny Observatory received from them the best large photographic refractor in the world. When the Canadian Government wished a six-foot re-

flector, the Brashear Company was commissioned to furnish the optical parts. How well they performed the task is attested by the work done by this telescope in the skilful hands of Dr. Plaskett and his assistants. Dr. Breashear always ascribed great credit to his son-in-law, Mr. James McDowell, upon whom, in later years, has devolved most of the optical work of the firm.

The key to the success achieved by him in his work was the fixed purpose of doing the thing in hand a little better if possible than any one else could do it. This explains why such fine instruments have gone out from his little shop. It is still too small to attract any attention from the passer-by, and was smaller still when he made his reputation by the instruments fashioned within its walls. He was not in business for the money which could be made out of it, since in the effort for perfection, instruments were often delivered which cost to produce several times the amount for which they were sold. But to a person deeply interested in his work, as was Dr. Brashear, the happiness acquired by doing his work as perfectly as possible compensates for other losses he may suffer. However, he had friends through whose aid he was able to give to the world the appliances which, in the hands of Langley, Keeler and others, have assisted so much in "Pushing forward the frontier of human knowledge". This inscription on a tablet on the Thaw Telescope, the largest refractor constructed by the Brashear Company, shows the spirit in which all his work was done.

Science owes much to the observer who, night after night, accumulates the observational data from which can be drawn far-reaching deductions; but we must not forget that he owes his success to the accurate work of the optician whose patience in producing a perfect optical surface may equal that of the observer who uses the fashioned instrument. Therefore, while Dr. Brashear did little astronomical work, his name will be indissolubly associated with the modern advance of the science, because he furnished the appliances without which this advance would have been impossible.

While his ashes lie mingled with those of his beloved wife in the crypt under the Keeler Memorial Telescope of the Allegheny Observatory, his memory will remain with the scientist as one who tried, as far as lay in his power, to assist him in probing into the

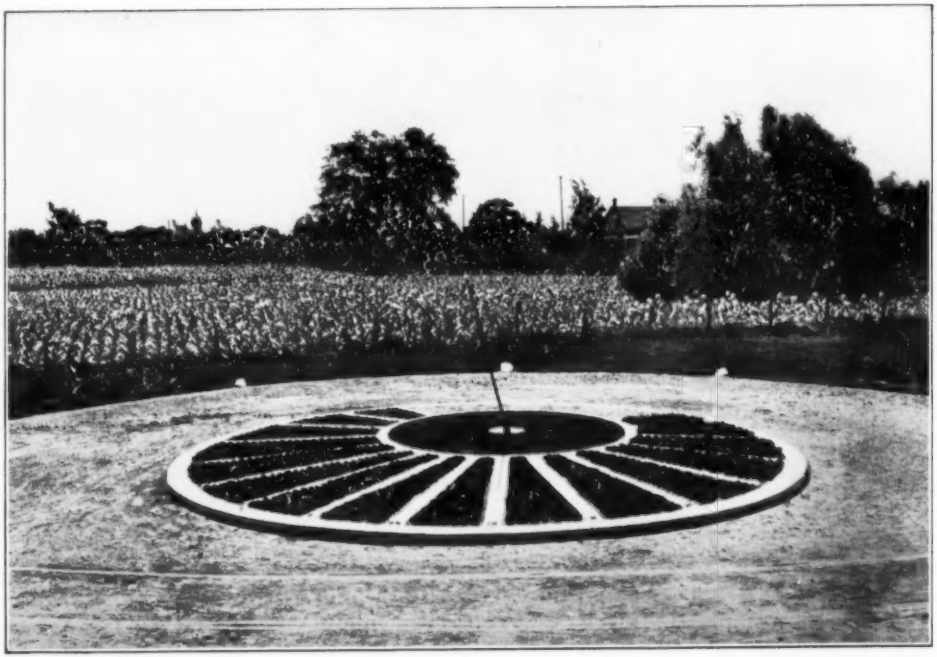
secrets of the universe; it will remain with the people of Pittsburgh as one who tried, as far as lay in his power, to make the world brighter and happier for his having lived in it.

Their hope for the future is beautifully expressed by the inscription on the urn which holds their ashes:

> "We have loved the stars too fondly
> To be fearful of the night."

ALLEGHENY OBSERVATORY,
PITTSBURGH, PA.

PLATE VIII.



SUN-DIAL AT THE DOMINION OBSERVATORY, OTTAWA.

Journal of the Royal Astronomical Society of Canada, 1920.

SUN DIALS

By Otto Klotz

Having been requested to design the hour lines for the sun dial on the Sussex Street side of the Grey Nuns' Convent here in Ottawa, it may be of interest to write a brief paper on the subject.

Those that have access to the *Encyclopaedia Britannica*, 11th Edition, will find several pages under the title "Dial", giving the history and the development of dialling or the construction of sun-dials. We will just note that the earliest mention of a sun dial is found in Isaiah xxxviii. 8: "Behold, I will bring again the shadow of the degrees which is gone down in the sun-dial of Ahaz ten degrees backward."

The most common form of dial is the horizontal one. One on a large scale is to be seen at the Observatory here, where the hour lines are separated by flower beds and of which a photograph is herewith given. (Plate VIII).

Let us make clear a few fundamental notions: The sun apparently moves uniformly around the earth, and uniformly whatever the declination of the sun, hence the apparent shadow of the earth's axis moves uniformly in a plane at right angles to it at 15° per hour, or 360°, the complete circle, in 24 hours. Now the sun-dial is simply a modified replica of this. The modification is that the shadow does not fall on a plane at right angles to the axis of the earth but on a horizontal plane, and this horizontal plane makes an angle with the earth's axis equal to the latitude of the place. We could make a dial with a rod and a disk at right angles to it, with the rod pointing to the north pole, thus representing the axis of the earth. On such a disk the shadow would be seen to travel uniformly from one hour line to the next, and so on. But such a disk is inconvenient for mounting and would require graduation on the lower and upper sides for south and north declination of the sun; so recourse is had to a horizontal plane, and the problem is simply to transfer the hour lines from the disk to the horizon, which is readily done graphically or mathematically.

The rod, or stylus or gnomon, is placed in the plane of the meridian and at an angle with the horizon equal to the latitude of the place. Obviously when the sun is in the meridian it is 12 o'clock sun time, or solar time or, as astronomers call it, apparent time.

Let PR (Fig. 1) represent the stylus, ϕ = the latitude, then the line RO at right angles to PR represents the trace of the plane in which the sun is moving around R, each such plane is parallel to the plane of the equator; and the line EOW represents the intersection of the above plane (in which lies RO) with the horizon. Let us revolve the plane of RO about O into the horizontal plane where $OR' = OR$, and the circle with $R'O$ for radius represents the uniform motion of the sun. Radial lines drawn from R' and the angles

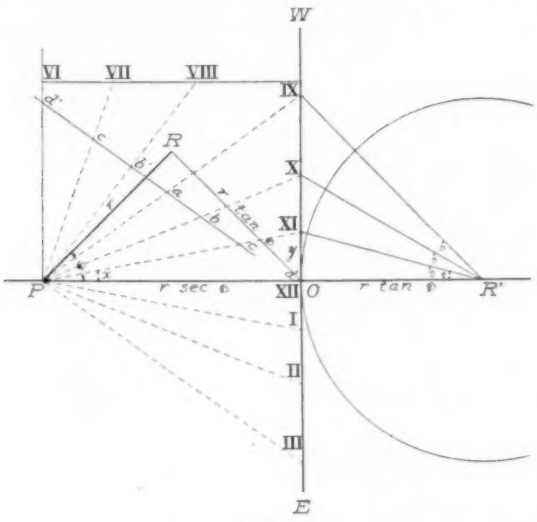


FIG. 1

made with $R'O$ the meridian are the hour angles, and their intersection with the line WOE will indicate the points where the shadow cuts the horizon. Hence any such point joined to the point P, the origin or foot of the stylus, will give the respective hour line for the dial.

The graphical construction is as follows: From R' draw lines R'XI, R'X, R'IX, making angles of 15°, 30°, 45° with $R'O$, join PXI, PX, PIX. Beyond IX or III it is generally not convenient to draw the other lines, so we have recourse to a geometrical device (the pretty solution is left to the reader) as follows:

On either the III or IX hour line take any point and draw a line parallel to the other; on this line lay off $ab'=ab$, $ac'=ac$, $ad'=ad$. The last might have been omitted, for in a horizontal dial the VI hour line is always at right angles to the meridian or XII hour line; also the a.m. and p.m. lines of the same hour are in a straight line through the foot of the stylus. So much for the graphical construction; now the mathematics thereof.

Reverting to the figure, let the length of the stylus be r, latitude be ϕ, and hour angle at R' be t, then

$PO=r \sec \phi$, $OR=OR'=r \tan \phi$, $OXI=y=r \tan \phi \tan t$, and the angle x on the dial for hour angle t is given by

$\tan x=y/r \sec \phi=r \tan \phi \tan t/r \sec \phi=\sin \phi \tan t$. Thus the various values found for x may be laid off for the respective hour lines of the dial.

It may be observed that for the large dial on the observatory grounds the values of y were computed for the five hours and laid off on a tangent line *EOW*. The points were joined with the foot of the stylus, giving thus the hour lines, which may be enclosed in a rectangular or circular or any other design.

In designing a large dial it is well to remember that the length of the shadow varies considerably during the year, being shortest at the summer solstice. The length of the rod should be such that its shadow at noon reaches to the end of the XII line as laid out on the dial.

Let us next consider a dial on a vertical wall and one running east and west, *i.e.* facing due south. Our diagram is very similar to the preceding one. The rod or stylus again represents the axis of the earth and is placed in the plane of the meridian, making an angle with the vertical wall equal to the complement of the latitude. Hence the angle on the dial representing any hour angle t is given by the relation,

$$\tan x=\cos \phi \tan t.$$

If r is the length of the stylus, its orthogonal projection on the meridian will be $r \operatorname{cosec} \phi$; y will have the same value as before, viz.: $r \sin \phi \cos \phi \tan t$. In the construction of the dial we may lay off y at right angles to the extremity of $r \operatorname{cosec} \phi$ or we may lay off the angles x from the above relation.

We see the construction of the vertical dial is almost identical with that of the horizontal one. The close relationship between

the two is well illustrated by a small model readily constructed. Nail two, say foot square, boards together and at right angles to each other. Stretch a stout string from one to the other at an angle to the horizontal board equivalent to the latitude of the place, the plane of the string being at right angles to both boards. Now set the boards so that the string is in the meridian. We have now a horizontal and vertical dial. The point to be brought out by the model is that the hour lines at the intersection of the two boards or horizontal and vertical planes, answer for both dials. The points along this line of intersection designate or indicate the position of the points found from the values of y above.

Now the last case of a dial to consider is the one that gave rise to this short paper; it is the case of a dial on a wall not running east or west, but making an angle (any angle) therewith.

Let the rod or stylus extend from one plane to the other and at the proper angle and in the plane of the meridian. In the above diagram (Fig. 2) P and P' are the extremities of the stylus and WOE the trace of the two planes. Obviously $PO = r \cos \phi$, $P'O = r \sin \phi$; y and x have the same meaning and value as before.

Let SX (Sussex) represent the direction of the wall on which the dial is to be constructed.

It remains to draw the hour lines on the latter wall. Let it be granted that the points for y have been established along WOE as before. Take one of them, α, with $P\alpha$ the particular hour line. This hour line cuts the trace of the wall at a, hence a is a point on the hour line on the wall while P', the extremity of the stylus where the shadows diverge, the other point. The angle θ at P' is given by the relation $\tan \theta = Oa/P'O$.

In the triangle $Oa\alpha$ we have $Oa = y = r \sin \phi \cos \phi \tan t$, $\tan x = y/r \cos \phi = \sin \phi \tan t$; the angle $aO\alpha = A$, and $Oa\alpha = 90° - x$, hence Oa or $K = y \cos x / \cos (A \mp x)$, and therefore $\tan \theta = k/r \sin \phi = \cos \phi / \cos A \cot t \pm \sin A \sin \phi$. Hence θ can be computed from this expression.

The graphical solution is very simple. Obtain the intersections a, b, c, d—for the hour angles 1^h, 2^h, 3^h, 4^h—given by the points α, β, γ, δ—for the various values of y. Transfer the distances Oa Ob, Oc—to the WOE line, whereby we obtain a graphical representation of $\tan \theta$ in having the two sides of the right angle triangle $P'O$ I, $P'O$ II, $P'O$ III.

It may be observed that while on a horizontal dial and a vertical one in the prime vertical the six hour line is at right angles to the meridian or XII hour line, this is not the case when the vertical wall is not in the prime vertical or an east west line. The intersection f of a line through P parallel to WOE with the line SX gives the distance Of to be laid off on WOE for the point of the afternoon VI hour line. When t exceeds 90° or 6 hours, tan t becomes negative and we measure from O in the opposite direction,

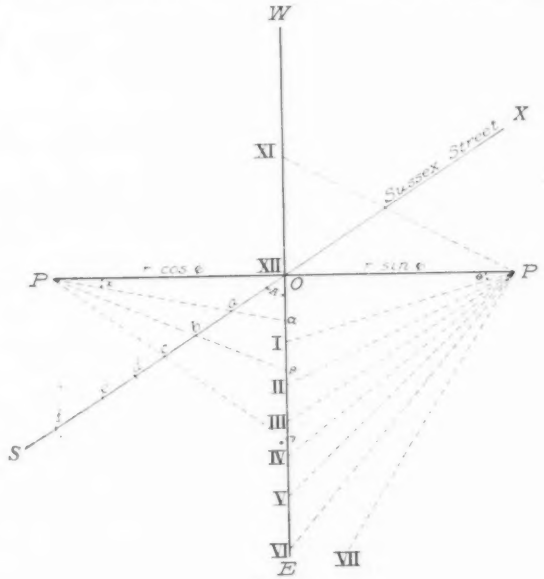


FIG. 2

and obtain an intersection through P with SX, giving us the distance to lay off from O for the hour angle in the above case 7p.m.

A closing word about solar time or the time shown by a sun-dial. Sun-dials at one time served a useful purpose, but to-day are only an ornament, a sentiment, a reminiscence of the days when there were few or no watches. Although the activities of life are regulated by or dependent upon the sun, yet the sun is a very poor time piece. For the purpose of illustration of the apparent shadow of the earth's axis we spoke of the motion of the

sun about the earth, of course it is the rotation of the earth that produces sun-rise and sun-set. The days as shown by a sun-dial are not of equal length, although the sun-dial shows the true solar time.

The inequality of the length of the days is due to two causes. In the first place the oribt of the earth about the sun is not exactly circular but eccentric so that the motion is not quite uniform, and furthermore the orbit is inclined to the plane of the equator which introduces another irregularlity in the length of the day. For purposes of life we have adopted days of equal length, that is, averaged up all the solar irregular days, into mean days. This is the time kept by watches and clocks. Four times a year the solar time and mean time are the same; on all other days a correction must be applied to the time shown by a dial to obtain the corresponding mean local watch time. It is perhaps a little too much to expect the man on the street to decipher the relationship between the time shown by a dial and our modern time-keeping. This is what he would have to do. He would have to apply for the particular day the correction, which at a maximum in November amounts to 17 minutes, to dial time to obtain local mean time. It will be observed that the word local is used, a time that is now practically obsolete in the civilized world; all local mean time having been replaced by standard time. The local mean time is the mean time for the particular meridian of the place (of the dial). To this we have to add or subtract the number of minutes and seconds that the place is east or west from the standard meridian—even hours from Greenwich—governing the time of the place. Here in Ottawa our local mean time is slow 2 minutes and 52 seconds on standard time. Having made the above two corrections, if it is summer we make another correction by adding an hour to our result, in order to obtain Daylight Saving Time.

We look at the dial, we look at our watch, and probably feel like saying, "Somebody is lying." At Port Arthur this difference may be over two hours, and the plaintiff would appear to have made out his case.

The sun-dial gives the correct sun time, our watches give the time to suit the convenience of man.

DOMINION OBSERVATORY, OTTAWA, CANADA.
January 21, 1920.

MEETINGS OF THE SOCIETY

At Toronto.

April 20.—The Society met in the Physics building of the University, at 8 p.m., the President, Mr. J. R. Collins, in the chair.

Mr. Miller stated that on April 11th, a large spot appeared on the sun's eastern limb, which he identified as having belonged to the group which caused the aurora of March 22nd. According to Greenwich there has been considerable activity in this locality for several months past. Mr. Jackson exhibited a slide showing the record of the magnetic disturbance of the 22nd, as obtained at the M eteorological Office. He read an extract from "Nature" of April 12th, referring to the observations made at Kew and Stonyhurst.

Mr. Hunter observed an aurora on the 17th, just 26 days after the aurora of last month, this interval corresponding to the rotation period of the sun. A singular halo was observed on the same day. About two degrees outside the ordinary primary circle, were two sun dogs, while a great white horizontal arc extended from one to the other, its altitude being equal to the altitude of the sun.

It is with great regret that the death of Dr. John A. Brashear on April 9th, is recorded. Dr. Brashear was the most distinguished manufacturer of optical instruments in the world, an honorary fellow of the Society and personally known to many of the members. It was moved and seconded that the President and Past President compose some mark of esteem for transmission to the immediate relatives of Dr. Brashear.

The paper of the evening was given by Dr. R. J. McDiarmid of the Dominion Observatory staff, his subject being, "Variable Stars". Variables are classified according to the changes in their light. Several distinct classes are recognized. Novae or temporary stars blaze out suddenly, gradually decline and after a few weeks or months, disappear. Irregular variables without any apparent law, such as Eta Carinae. There is no satisfactory explanation for this class. Regular variables of a long period, such as o Ceti (Mira) which was discovered by Fabricus in 1596. During most of the time it remains invisible, but every eleven months it increases to the third or even second magnitude, then dies away again. Regular variables of a short period, such as Algol. Algol was discovered by Goodricke in 1783, who gave the correct explanation, which however was not proven until 1880. The system consists of a bright star and a dark body, revolving about their common centre of gravity. The dark body periodically eclipses the brighter one. In the case of Algol the light varies from the 2nd to the 4th magnitude, the

period being 68 hours 48 minutes and the eclipse lasting for some 9 hours. The spectroscope reveals the Doppler Principle, which proves that the bright body is alternately approaching and receding from the earth during a period. By a study of the spectral lines the system may be completely analyzed, the masses of the bodies and their velocities in their orbits may be found. The light curves and velocity curves enable one to determine the elements of the orbit. The light and velocity curves of many of the eclipsing variables were shown and the lecturer illustrated the binary systems with his electric models.

May 4.—The Society met at 8 p.m. in the Physics Building of the University of Toronto, the President, Mr. J. R. Collins, in the Chair.

The following were nominated for membership: Wilson Taylor, B.A., Toronto; Jamieson Bone, Belleville.

Mr. A. F. Miller described the conditions of the eclipse of the moon on the night of May 2nd, which were unsatisfactory owing to cloudiness. He had observed Mars with the telescope on every possible occasion, but scarcely any details on its surface were visible to him at its present return to opposition, using a telescopic power of 400.

An account of the total eclipse of the moon on May 2nd by Mr. A. R. Hassard was read by Prof. Chant.

Mr. Allan F. Miller gave the paper of the evening on "The Story and Poetry of the Zodiac". He defined a myth as a story with a meaning different from what it has at first sight. The myths of the zodiac, like those of the other stars and constellations, were connected during early stages of civilization with actual events in ordinary life, and were not utterly false or misleading. The love stories of the gods, which have some place amongst astronomical myths, arose through ancestor worship, *i.e.*, tracing family ancestry back to some deity. It was natural that their exceptional virtues should be transferred as memorials to the map of the skies. He described the close association of the Zodiac with early religious beliefs, and gave in order the Zodiacal constellations with the signs, myths and poetry connected with them. The lantern slides used to illustrate the paper showed various Egyptian religious objects and rituals, also different charts of the Zodiac, in particular the Zodiac of Dendera in Upper Egypt, found in 1822 and preserved in Paris Museum, which shows the same signs as are now in current use as the present names of the twelve signs. This fact shows that the Dendera Zodiac was not a very ancient compilation.

J. A. PEARCE, *Recorder.*

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada
March, 1920

Temperature

The temperature over a considerable portion of British Columbia and at a few points in the Western Provinces was slightly below the average, elsewhere in the Dominion it was above the average, Ontario registering the greatest positive departure, amounting to from 3° to 5°.

Precipitation

The precipitation in British Columbia was nearly everywhere well above the average, with a heavy snowfall on the mountains, the Glacier in the Selkirks registering 84 inches of snow, which is 30 inches more than the average amount. In Cariboo also the snowfall was much heavier than usual. In the Western Provinces preciptiation was for the most part above the average, but in some few localities there was a deficiency, chiefly in Southern Alberta and Southwestern Saskatchewan. In Ontario in the Lake Superior District it was rather more than usual, as it was also at a few scattered points elsewhere, but over a large portion of the Province there was a deficiency, and in many places to a marked extent. In Quebec, over the Western half of the Province there was a small excess, with a deficiency over most of the Eastern portion. In the Maritime Provinces in the vicinity of St. John and over the Annapolis Valley there was a large excess, chiefly owing to the exceptionally heavy rainfall in those districts on the 13th, elsewhere, however, the amount fell short of the average by about one to two inches.

April, 1920

Temperature

The temperature was below the average throughout the Dominion, the negative departure being especially pronounced in the Western Provinces, where it ranged from 9° to 14°. In British Columbia and Ontario the deficiency was from 3° to 6°, and in Quebec and the Maritime Provinces from 1° to 2°.

Precipitation

In British Columbia the precipitation was above the average, except in a few scattered localities. In the Western Provinces there was an excess in Southern Alberta, and a deficiency elsewhere, especially in Manitoba. In Ontario there was a little less than usual in the Lake Superior district and at a few other points, but over the greater portion of the Province the average amount was exceeded. In Quebec and the Maritime Provinces there was an excess in all localities. Some of the chief positive departures were Sydney, C.B., 4.80 inches; Halifax, 4.00 inches; Quebec City, 3.58 inches; Mount Forest, Ont., 2.67 inches; and Barkerville, B.C., 2.80 inches; while the chief negative departure was reported from Winnipeg, and amounted to 1.20 inches.

MAGNETIC DISTURBANCES, APRIL-MAY, 1920.

No very noteworthy disturbances were recorded during April and May at Agincourt or Meanook Magnetic Observatories. The accompanying table gives particulars of the moderate ones.

75th M. T.				Range			
Beginning		Ending		Ag H.	Ag. Z.	Ag D.	Me. D.
	h m		h m	γ	γ	° ′	° ′
April 14	19 —	April 15	24 —	367	315	1 11.1	3 49.9
April 16,	21 19	April 18,	24 —	266	279	0 54.2	3 09.0
April 30	11 —	May 1	11 —	327	296	0 49.0	1 59.6

The aurora was not reported by Meteorological Observers in Canada during April and May as frequently as in former months, and when visible was usually of the 3rd or 4th class. The only first class aurora was reported from Ontario to the Atlantic on the 22nd of April, at which time the magnetic curves were calm.

Sunspots were also few in number and small in size, and on April 8th and 23rd the sun's visible surface was free of spots.

TEMPERATURES FOR MARCH AND APRIL, 1920

STATIONS	MARCH		APRIL	
	Highest	Lowest	Highest	Lowest
Yukon				
Dawson	30	−38	50	−30
British Columbia				
Atlin	36	−21	47	−23
Agassiz	61	26	74	27
Barkerville	44	− 9	49	− 8
Kamloops	60	13	76	13
New Westminster	60	28	66	29
Prince Rupert	46	26	58	22
Vancouver	59	28	64	31
Victoria	59	32	65	30
Western Provinces				
Battleford	50	−25	52	−12
Calgary	56	−22	57	− 8
Edmonton	49	−18	54	−15
Medicine Hat	62	−24	66	− 2
Minnedosa	46	−28	52	−14
Moosejaw	58	−23	56	− 2
Oakbank	48	−19	57	− 2
Portage la Prairie	—	—	61	2
Prince Albert	46	−25	56	−15
Qu'Appelle	47	−24	51	−10
Regina	48	−34	54	− 7
Saskatoon	46	−24	56	− 6
Souris	43	−27	54	−13
Swift Current	58	−22	58	2
Winnipeg	50	−19	56	− 2
Ontario				
Agincourt	66	− 9	62	19
Oak Ridges	61	− 9	60	15
Bancroft	62	−25	65	15
Beatrice	63	−17	64	13
Bloomfield	63	− 5	65	12
Brantford	73	0	—	—
Chapieau	60	−30	59	2
Chatham	73	5	67	17
Clinton	66	− 7	63	9
Collingwood	65	0	70	5
Cottam	68	5	—	—
Georgetown	66	− 9	64	15
Gravenhurst	68	−13	65	11
Grimsby	68	− 2	66	16
Guelph	66	−12	62	15

STATIONS	MARCH		APRIL	
	Highest	Lowest	Highest	Lowest
Ontario—continued				
Haliburton	64	−21	68	4
Huntsville	69	−20	69	12
Kenora	56	−18	57	− 5
Kingston	63	− 6	63	17
Kitchener	68	− 8	67	10
London	71	2	68	16
Lucknow	66	−13	62	5
North Gower	—	—	65	25
Oshawa	33	9	—	—
Ottawa	66	−19	67	19
Paris	70	− 8	66	15
Parry Sound	58	−12	67	14
Peterborough	66	−12	67	16
Port Arthur	50	−10	55	2
Port Burwell	68	6	68	20
Port Dover	64	0	62	18
Port Stanley	59	5	66	18
Queensborough	58	−22	69	17
Ronville	62	−19	64	12
Southampton	66	−12	64	15
Stonecliffe	70	−18	66	10
Stoney Creek	69	− 6	68	20
Toronto	66	− 1	60	18
Uxbridge	65	−18	62	9
Wallaceburg	60	—	72	19
Welland	75	− 6	67	17
White River	55	−33	56	− 6
Quebec				
Bromé	53	−32	61	13
Father Point	56	−10	54	18
Montreal	60	− 7	62	22
Quebec	60	−18	62	17
Sherbrooke	64	−22	61	19
Maritime Provinces				
Charlottetown	58	− 6	52	18
Chatham	66	−22	60	16
Fredericton	65	−19	67	15
Halifax	68	−10	62	24
Moncton	61	−10	55	19
St. John	58	− 8	62	20
Sussex	55	−17	68	12
Sydney	64	− 2	56	20
Yarmouth	58	2	64	28

EARTHQUAKE RECORDS BY MILNE SEISMOGRAPH, TORONTO

SIR FREDERIC STUPART, F.R.S.C., DIRECTOR

P.T. = Preliminary Tremors. S. = Secondary Waves. L. = Large Waves. A.C. = Air Currents. Time is Greenwich Mean Civil Time; it is to be given in hours, minutes and decimals of minutes; *0* or 24 h = midnight.

No.	Date 1920	P. T. Comm.	S. Comm.	L. W. Comm.	Max.	End	Max. Amp.	Remarks
		h m	h m	h m	h m	h m	mm.	
2118	Mar. 9			4 51.9			0.05	
2119	" 10			16 32.2			0.05	Micros at intervals.
2120	" 12			16?27.9			0.1	
2121	" 12			18 31.3			0.2	Micros.
				18 37.2				
2122	" 13			5 04.8	5 07.9		0.3	Micros.
2123	" 15	12?25.1	12 34.7	13 02.1	13 11.8	14 23.1	2.4	8330 Km.
				13 04.7				
2124	" 20			0 07.6	0 00.5	0 10.7	0.2	
2125	" 20	Att'g ins	tr.18?09.6	18 12.4		18 22.2	0.2	May be West Indies.
2126	" 20	18 42.8	18 54.8	19 07.6	19 18.6	20 50.3	1.4	Repeat 20h. 45.5m.
				19 17.2				
2127	" 22			2 00.7			0.2	L waves abnormal.
				2 20.5				
2128	" 22		20?42.3	20 58.5	21 05.7	21 40.8	0.5	
				21 0 .1				
2129	" 23	15?25.2	15 32.3	15 36 4	15 45.6	16 16.2	0.7	5440? Km.
				15 41.1				
2130	" 29		5 20.6	5 26.	5 27.5	6 21?9	2.2	4414 Km.
2131	April 2			2 10.4	2 17.7	2 47.3	0.2	
				2 11.5				
2132	" 6		17?03.2	17 09.9				Light turned down at 17h. 13m.
2133	" 6			19?37.1			0.05	
				19 46.2				
2134	" 6			20 04.3	20 17.8		0.1	
				20 16.3				
2135	" 6			21 12.4	21 17.8	21 23.6	0.2	
2136	" 9			15 07.4			0.05	
				15 10.8				
2137	" 11			23 30.7			0.05	
				23 48.9				
2138	" 16			22 57.3	23 04.3	23 39.0	0.3	
				23 03.3				
2139	" 18			21?26.3				Paper being paid out irregularly. Reading doubtful.
2140	" 19	21 13.4	21 17.6	21 30.0	21 33.0		0.4	P very minute. May be a dual eq.
			21 19.0					

Period of Boom 18 seconds. Pillar inclination 1 mm. = 0″.45.

EARTHQUAKE RECORDS BY MILNE SEISMOGRAPH, VICTORIA, B.C.

F. NAPIER DENISON, SUPERINTENDENT

No.	Date 1920	P. T. Comm.	S. Comm.	L. W. Comm.	Max.	End	Max. Amp.	Remarks
		h m s	h m s	h m s	h m s	h m s	mm.	
2110	Mar. 9			4 51 35			0.2	
2111	" 11			12 53 44			0.05	
2112	" 11			19 20 49			0.05	
2113	" 12			16 05 46		16 26 54	0.2	
2114	" 12			18 17 34	18 27 24	18 37 43	0.3	L may be S phase.
2115	" 13			4 40 43	4 47 36		0.3	
2116	" 15	12 19 25	12 28 16	12 39 35	12 48 55	13 28 16	0.5	7420 Km. Prob. Japan or Peru.
2117	" 20			0 03 17	0 14 06	0?23?56	0.3	
2118	" 20			17 42 39	17 43 38		0.2	
2119	" 20			17 52 00	17 53 28	18 24 28	1.0	
2120	" 20	18 45 07	18 54 27	19 06 16	19 14 38	21 21 17	2.0	8000 Km. Prob. apan or Peru.
2121	" 22				0 06?22	0 18 10	0.1	
2122	" 22				2 23 05	2 41 46	0.3	
2123	" 22	20?22 10		20 36 26	20 43 10	21 07 28	0.4	
2124	" 23	15 35 16		15 43 11	15 46 40	15 59 34	0.4	
2125	" 29	5 09 15		5 09 44	5 11 13	6 17 36	17.5	220? Km. Prob. E. Washington or W. Montana.
2126	April 2	1 43?31			1 54 20	2 15 00	0.2	
2127	" 2				7 53 00	7 58 46	0.2	
2128	" 2	15 37 38			15 46 49	16 13 13	0.3	
2129	" 6	16 57 16		17 03 40	17 07 36	17 26 47	0.5	P may be S phase.
2130	" 6		19?18 26	19 23 51	19 31 43	20 24 20	0.5	
2131	" 6				21 25 19	21 27 17	0.1	May not be seismic.
2132	" 9	15 07 08			15 14 04	15 21 01	0.2	
2133	" 10				8 36 49		0.1	
2134	" 11	23?14 11		23 20 35	23 27 28	23 37 18	0.2	P may be S phase.
2135	" 16			22 41 06	22 50 27	23 22 25	0.2	
2136	" 18			21 14 51	21 16 20	21 24 46	0.4	
2137	" 19	21 15 50	21 19 17	21 24 12	21 29 36	21 53 12	1.0	2030 Km.

Period of Boom 18 seconds. Pillar inclination 1 mm =0″.54

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries

A HUGE METEOR REPORTED IN OKLAHOMA

Prominence was given in the daily papers of June 9th to a Press Despatch reporting the fall of a huge meteor near Okmulgee, Okla.; but a closer examination of the report shows an indefiniteness and lack of detail so often found in such statements. It states: "Geologists were expected to examine to-day a huge meteor which fell and burned itself out near here last night, after lighting the skies over several southwestern states". Just what is meant by *burning itself out* is uncertain, and it suggests that the body disappeared in the process. At Tulas, Okla., the meteor appeared to be only a few hundred feet above the earth (evidently an illusion), while an "astronomic authority" down there said he believed the meteor was thrown off from a destroyed planet between Mars and Jupiter as it appeared to travel from west to east! If the body has actually been found we should look for some account of it in the scientific journals.

Some Publications Received

The Tides and Tidal Streams, with illustrative examples from Canadian Waters is the title of a 48 page pamphlet by Dr. W. Bell Dawson, of Ottawa, published by the Department of the Naval Service, Ottawa. Dr. Dawson has long been recognized as our greatest authority on this subject and the account he gives of the various types of tides found on our shores is interesting and well worth reading. I have no doubt our readers can obtain a copy by addressing him at the Department of the Naval Service, and a study of the publication will add to one's education.

Volume I, number 1, of the *Publications of the Dominion Astrophysical Observatory* at Victoria, B.C., has made its appearance. It extends to 103 pages, $9 \times 11\frac{1}{2}$ inches in size, and contains a description of the building and equipment. In the present issue of the JOURNAL is an interesting paper on the subject by the Director.

The *Annual Report* of the Superintendent of the Geodetic Survey of Canada for the year ending March 31st, 1919, prepared by Noel Ogilvie, Superintendent, contains an outline of the work done and is illustrated with many interesting figures and maps.

In the *Transactions of the Cambridge Philosophical Society*, Vol. 22, Oct. 1919, is an extensive mathematical paper entitled "Asymptotic Satellites near the equilateral-triangle equilibrium points in the problem of three bodies", by Prof. Daniel Buchanan of Queen's University, Kingston. This is an important contribution to one of the greatest problems of theoretical astronomy.

The Parallaxes of Fifty Stars (second list) is No. 5 of the Sproul Observatory Publications, Swarthmore, Pa. It was prepared by Prof. John A. Miller, the director, with the co-operation of John H. Pitman and Hannah B. Steele, and it shows how rapidly the measurement of the distances of the stars is proceeding. It is interesting to note that the *greatest* parallax obtained is that of a ninth magnitude star, its value being 0".146, indicating that its distance is about 23 light years.

Part 6 of Vol. II of the *Publications of the Leander McCormick Observatory* of the University of Virginia contains an account of the Total Solar Eclipse of 1918, by the director Dr. S. A. Mitchell and an article on "Painting the Solar Corona" by Howard Russell Butler, N.H. Dr. Mitchell observed the eclipse at Baker City, Oregon, and under his direction Mr. Butler made sketches from which afterwards he worked out a beautiful painting of the eclipsed sun. This is skilfully reproduced in colours.

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Dr. Otto Klotz, Director of the Dominion Observatory, was recently elected, at San Francisco, President of the Seismological Society of America.

C. A. C.

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